

Intertidal communities as indicators of environmental change and their potential use in biomonitoring: The Troia Resort (Portugal), a large-scale tourist development, as a case study

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ABSTRACT

Sandy beaches are the key attraction in coastal tourist projects, and are directly affected by such uses as construction of infrastructure and recreation.

Benthic communities integrate, in space and time, the variability of the environment they occupy, and constitute useful indicators of the environmental change induced by projects built on the shoreline. Their study can, therefore, assist decision-makers in the management of these sensitive areas.

In the framework of the environmental assessment of the construction of a marina and a ferry harbour for a tourist resort in southwest Portugal, the benthic intertidal communities were studied, and provided useful indications for the management of the area.

Some advantages of monitoring benthic communities are discussed, as well as the use of related scientific information on the continued environmental project management.

Keywords: Environmental management, benthic communities, sandy beaches, biomonitoring, participative management.

RESUMEN

Utilización potencial del control de las comunidades bentónicas intermareales como indicador de la alteración ambiental: Troia Resort (Portugal), un proyecto turístico de gran escala, como caso de estudio

Las playas arenosas constituyen la atracción principal en los proyectos turísticos costeros, y los usos recreativos y la construcción de infraestructuras las afectan directamente.

Las comunidades bentónicas integran espacial y temporalmente la variabilidad de los ambientes que ocupan; por tanto, pueden constituir indicadores útiles de la alteración ambiental resultante de los proyectos desarrollados en las costas y, así, contribuir a la toma de decisiones adecuadas en la gestión de áreas sensibles.

Con el objetivo de evaluar el impacto ambiental de la construcción de un centro náutico y un puerto para transbordadores, ambos integrados en un complejo turístico en el suroeste de Portugal, se estudiaron las comunidades bentónicas intermareales cercanas, y resultaron ser indicadores útiles para la gestión de esas áreas.

En este trabajo se exponen y discuten algunas ventajas del control de las comunidades bentónicas y la orientación de esta información científica al servicio de la gestión ambiental en este tipo de proyectos.

Palabras clave: Gestión ambiental, comunidades bentónicas, playas arenosas, seguimiento biológico, gestión compartida.

INTRODUCTION

For tourist projects located on temperate to warm coasts, beaches are one of the key attractions. Concurrently, sandy intertidal areas are the dynamic systems that suffer the impacts of both direct uses, such as recreation (beach use) and occupation (construction of harbour structures such as marinas), and indirect uses resulting from nearby urban occupation (e.g., Andrade, 1997; Bird, 1996; Carter, 1995). However, neither their dynamic behaviour, nor their ecological structure, are typically integrated into the design and management of projects on, or in direct connection to, the coast.

During the 1960s, a project was developed to build a major tourist resort in Troia, a pristine sandy peninsula 15 km long, located in the mouth of the Sado estuary, about 40 km south of Lisbon (figure 1). The project, which would have a capacity of 25 000 beds distributed over the northernmost 4.5 km of the peninsula, failed before full completion, never having attained significant levels of occupation.

In 1998, the remains of that tourist project were bought by a private investor (Imoarea, S.A.) who, as a first management measure, commissioned a strategic environmental study of that area of the peninsula (Andrade *et al.*, 1998). This study, which included the analysis of the shoreline variation over the previous 50 years, together with a preliminary assessment of terrestrial plant cover and soil maturity, made it possible to define a sensitivity gradient and the designation of preferential areas of occupation.

Meanwhile, a management plan was developed by the local municipal authorities, which limited the occupation of the same area to a maximum of 7 430 beds, and proposed the construction of a ma-

rina and the relocation of the existing ferry harbour.

To identify the best possible location for the new structures, and to evaluate their impacts and those resulting from the increased use of the beach area by tourists, a broader multidisciplinary study was undertaken in Troia (Andrade and Joanaz de Melo, 2003).

For the study of sandy intertidal environments, one of the areas directly impacted by the projects and by increased human pressure, we decided it would be better to use an integrative approach based on the study of benthic communities as opposed to the monitoring of discrete environmental parameters, since they integrate, in space and time, the variability of the environment they occupy. The present paper aims to highlight the importance of intertidal benthic communities in the evaluation of the environmental sensitivity of a coastal area that will be impacted by a large tourist project.

Some of the advantages of monitoring benthic communities are discussed, as well as the use of the corresponding scientific knowledge to inform a participatory environmental management process, both at the key stakeholder and public levels (Costanza *et al.*, 1998, 1999).

MATERIALS AND METHODS

From April 1999 to March 2000, the intertidal area of the northern tip of the Troia peninsula, from its outer to its inner margin, was monitored monthly, during the lowest spring tides, along 13 predefined transects, anchored at the base of the dune (figure 2).

Transects were profiled using a simple topographic technique (Andrade and Ferreira, submitted), to measure absolute height above Hydrographical Zero (HZ) and slope.

For sampling purposes, each transect was stratified into supralittoral, midlittoral and infralittoral levels, defined visually, by beach slope and morphology.

At each level, two replicate 50 cm³ sediment samples were taken with a small cylindrical plastic corer, 2.5 cm in diameter and 10 cm deep.

One of these samples was used for grain size analysis of the sandy fraction (Φ_{-1} , Φ_0 , Φ_1 , Φ_2 , Φ_3 , Φ_4), and the other replicate for the quantification of organic matter and carbonate contents through the process of loss on ignition at 500 °C and 800 °C,

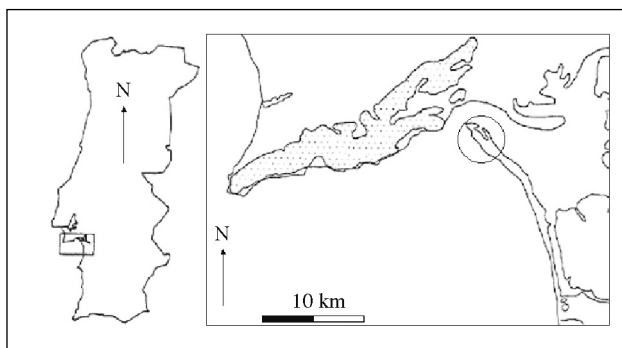
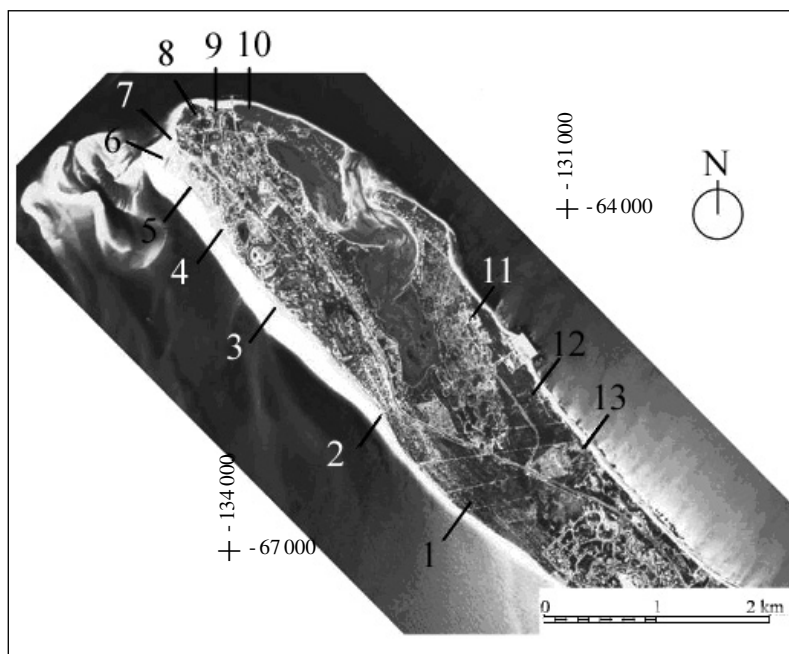


Figure 1. Location of Troia on the Portuguese coast

Figure 2. Location of the 13 profiles established in Troia (sothwestern coast of Portugal)



respectively (Byers, Mills and Stewart, 1978; Kristensen and Andersen, 1987).

Two replicate samples of 3.3 l of sediment were also taken with a metallic sand corer, 14.5 cm in diameter (165 cm²) and 20 cm deep, and sieved on the spot to study and quantify macrobenthic fauna (1 mm² mesh size).

This sample size was chosen both for practical reasons (a total of 40 locations along 7 km of shoreline were sampled monthly during the 4 lowest spring tides) and because it compares favourably with previous work on the area: e.g., Dexter (1990) sampled 2 × 100 cm² per site.

Animals were sorted shortly after collection, while still alive (Ferreira, 2001), and preserved in a 70 % alcohol solution (Saldanha, 1972). Laboratory determinations were later carried to the lowest possible taxonomic level and individuals were counted per taxon identified. During the study period, 480 samples were taken, from which 207 taxa were identified and quantified as no. indiv/m². Species richness, Shannon-Wiener diversity, and evenness were calculated for each sample.

To try to identify communities, Principal Components Analysis (PCA) was applied to a reduced biological matrix with 480 samples × 59 taxa, where density data was standardised per taxon (reduced and centred). A cut-off occurrence frequency of 2.5 % was used to reduce the biological data, thus ensuring that each taxon retained could oc-

cur, on average, at least once per month or once per transect (2.5 % corresponding to 12 occurrences in the 480 total samples considered).

From the reduced biological matrix, dominance, constancy and fidelity indexes –adapted from Cancela da Fonseca (1989)– were then calculated for each community as:

- Numerical dominance: 100 [(no. organisms taxon A)/(total no. organisms in the community)]
- Constancy: 100 [(no. occurrences of taxon A in the community)/(no. samples in the community)]. Only two classes were considered: 50-100 % (constant taxa) and 0-49.9 % (accessory taxa)
- Fidelity: 100 [(constancy of taxon A in the community)/(sum of constancies of taxon A in all the communities)]. Only the characteristic taxa with a fidelity > 50 % are mentioned in the results: 90.1-100 % (exclusive taxa), 67-90 % (selective taxa) and 50.1-66.9 % (preferential taxa)

RESULTS

Several concurrent environmental gradients were detected in the study area, from the outer to the inner margin of the peninsula. Beach profiles shifted from mainly reflective and variable/dynamic on the marine shore to mainly dissipative and temporally homogeneous on the estuarine margin (figure 3).

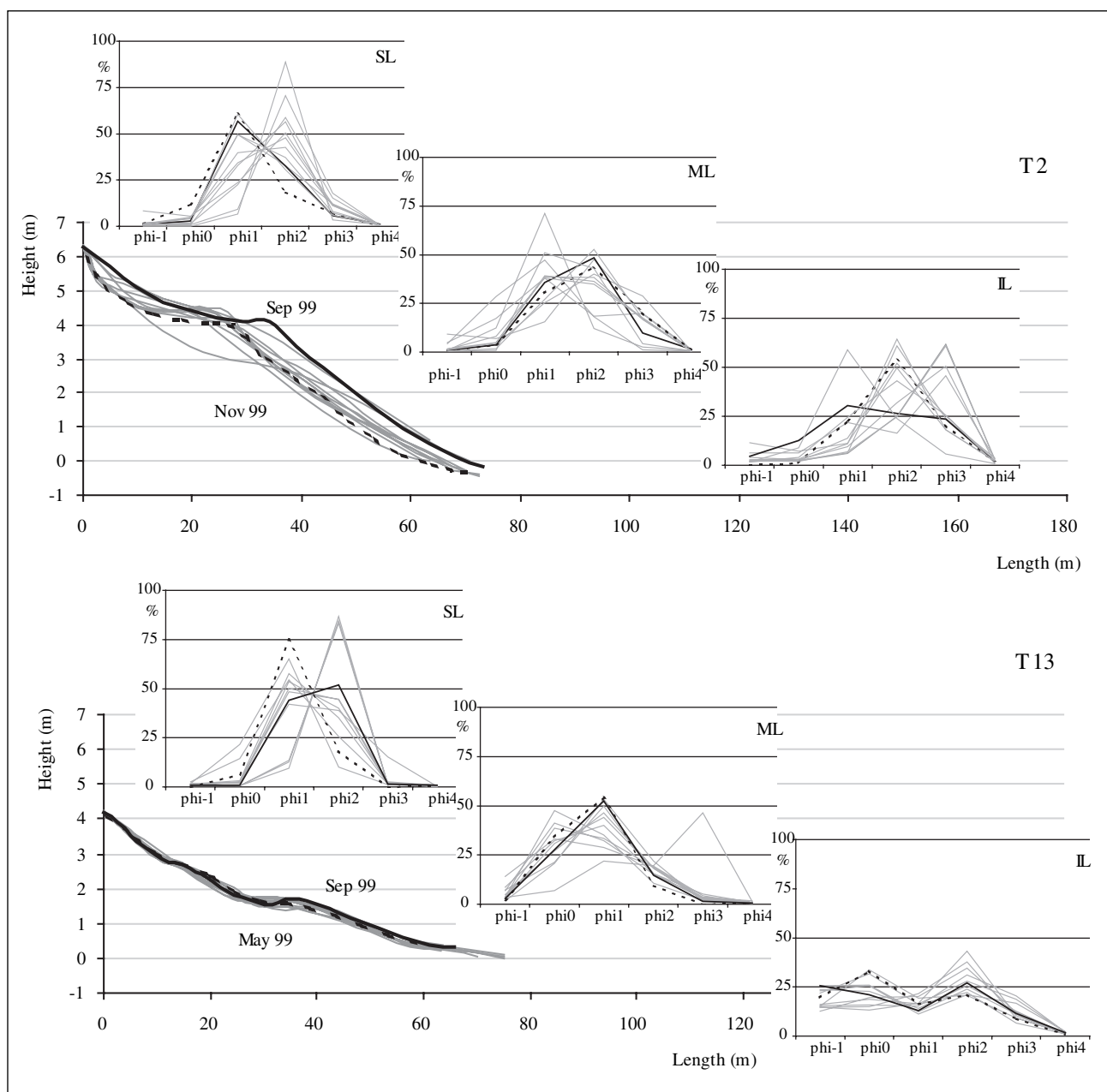


Figure 3. Beach profile and granulometry variation throughout the study period for two selected representative transects, T2 on the exposed marine shore and T13 on the sheltered estuarine shore (see figure 2 for locations)

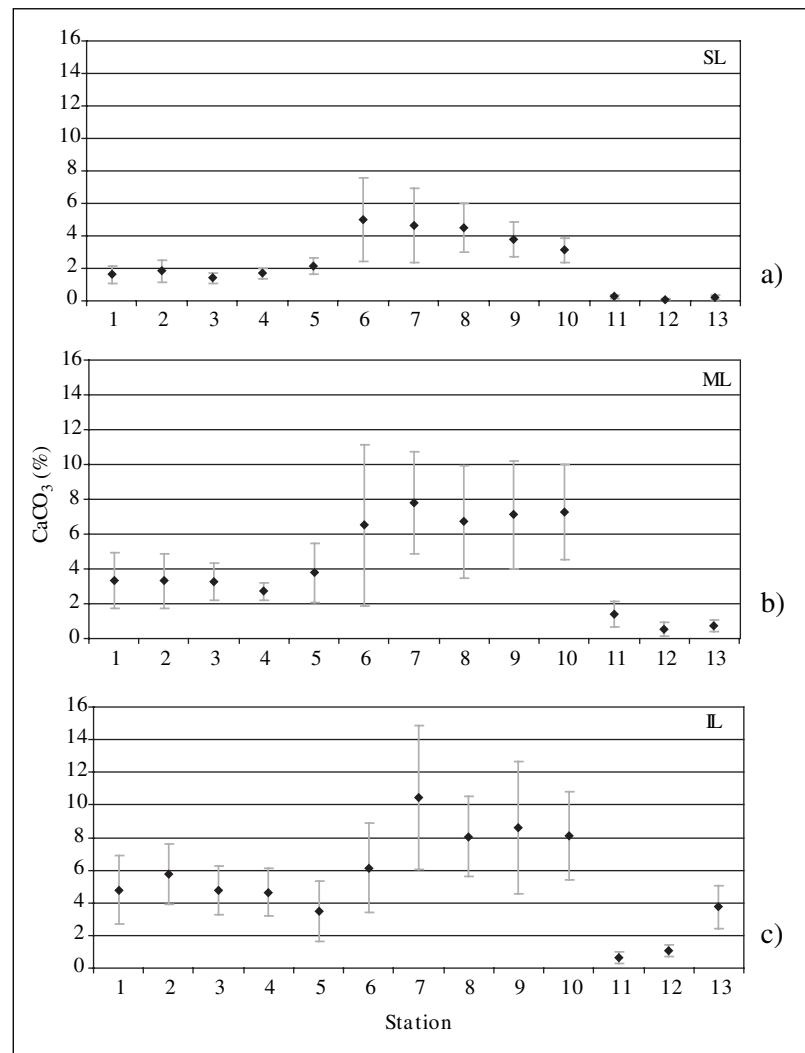
Sediments varied from medium, well-calibrated sands on the marine margin to heterogeneous sediments, including silt and gravel, on the estuarine shore. Together with grain size distribution, carbonate contents mark a clear difference in sediment sources: conchiferous sand on the marine side of the peninsula and riverine sediments on the estuarine margin. The tip of the peninsula (transects 6 through 10) showed the highest carbonate contents, in correspondence with the deposi-

tion/accretion area where marine and riverine influences meet (figure 4).

Organic matter contents were consistently low ($< 1\%$), but showed vertical (decreasing with height above HZ) and horizontal gradients at the infralittoral level, with a slight tendency to increase toward the estuarine side of the peninsula (figure 5).

Principal components analysis of the distribution of samples in the taxa space (figure 6a) clearly separated the inner estuarine infralittoral sam-

Figure 4. Sediment carbonate contents (10-month averages and standard deviations) at each sampling station. (a): supralittoral; (b): midlittoral; (c): infralittoral



ples (transects 11-13) and the infralittoral samples in the vicinity of *Zostera* spp. beds at the tip of the peninsula (transects 7 and 9).

Contribution of the taxa to principal axes 1 and 2 (figure 6b) suggested the presence of three additional communities: supralittoral, midlittoral, and a third, poorer infralittoral community, predominantly corresponding to the marine side of the peninsula.

Constancy and fidelity indexes for each community are summarised in table I.

The supralittoral community was dominated by talitrid amphipods, *Tylos latreillei* Audouin, 1826, and insects, occurring in medium sands, with very low organic matter contents.

The midlittoral community was well separated from the above and corresponded to intermediate shore levels with medium to coarse sands, sometimes with high carbonate contents. It was domi-

nated by the polychaetes *Scolecopsis squamata* (Müller, 1806) (= *Nerine cirratulus*) and *Ophelia bicornis* Savigny, 1818.

Both supra- and midlittoral communities were homogeneous throughout the study area, and are characteristic of naturally stressed environments in marine temperate regions (Colombini *et al.*, 1996; Elkaim, 1976; Fallaci *et al.*, 1996; Raffaelli and Hawkins, 1996). In Troia, they were found to be poorly structured, resilient, well defined, and both temporally and spatially stable.

The infralittoral level was found to be a heterogeneous environment, with three different communities showing increased structural complexity from the sea to the estuary:

- A community dominated by *Angulus* (*Tellina*) *tenuis* (Da Costa, 1778) and *Nephtys* sp., predomi-

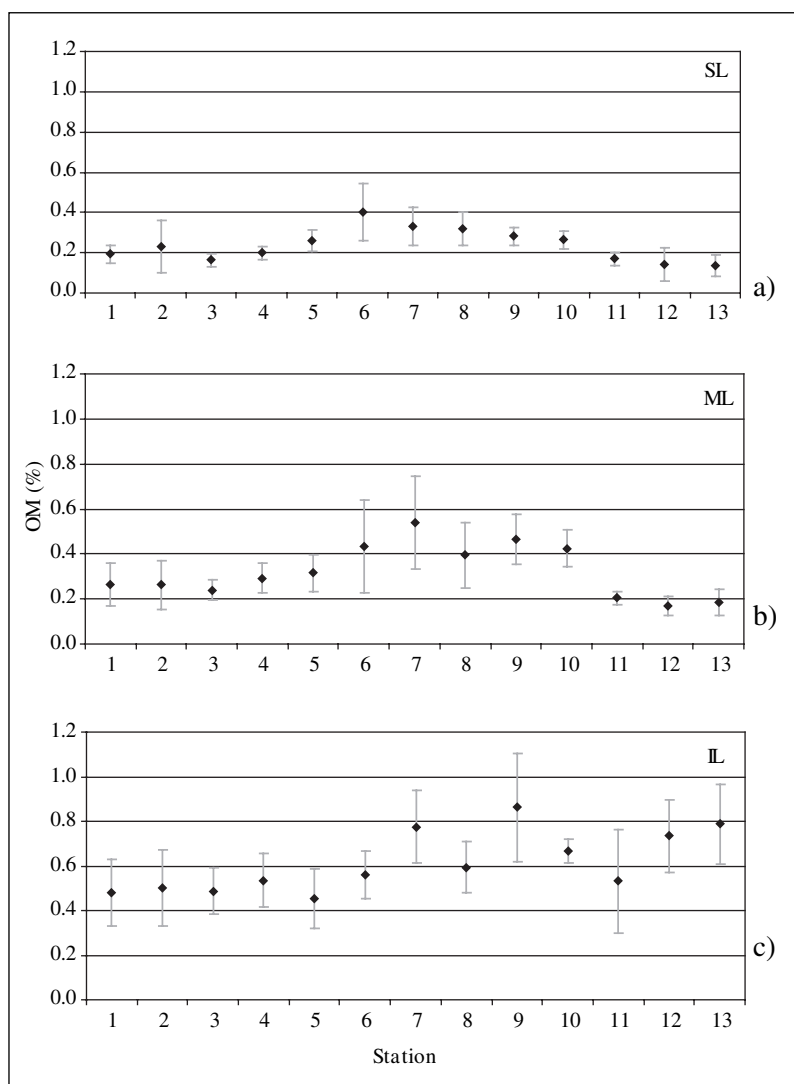


Figure 5. Sediment organic matter contents (12-month averages and standard deviations) at each sampling station. (a): supralittoral; (b): midlittoral; (c): infralittoral

nantly on the marine and more dynamic side of the peninsula, where the lowest organic matter content and a higher proportion of medium to fine sands were found. The most characteristic species was *Haustorius arenarius* (Slabber, 1769). This seemed to be the base infralittoral community in the area, characterised by low densities and diversity.

- In the sea-estuary transition, in areas with higher stability, associated with patches of *Zostera* spp. (transects 7 and 9), the community is numerically dominated by the polychaete *Euchlymene* sp. A, and characterised by the presence of *Onuphis eremita* Audouin & Milne-Edwards, 1833; *Sphaeroma monody* (Fabricius, 1787); *Ophelia laubieri* Bellan & Costa, 1987; *Pariambus typicus* (Kroyer, 1844); *Bodotria arenosa* (Goodsir, 1843) and *Divaricella divaricata* (Linnaeus, 1758). This community showed rela-

tively high densities, species richness, and diversity, but low evenness values (figures 7c and 8c).

- On the estuarine margin of the peninsula, in the area of maximum stability, with higher contents of organic matter and dense *Zostera* spp. beds, the most structured community was found, numerically dominated by the polychaete *Spiochaetopterus costarum* (Claparède, 1870) and with 4 exclusive taxa: *Melinna palmata* Grube, 1870; *Diopatra neapolitana* delle Chiaje, 1841; *Nucula* sp. and *Abra alba* (Wood, 1801).

The integration of these results made it possible to define a zonation scheme based on a gradient of increasing sensitivity from the sea to the estuarine margin of the peninsula, and from the highest to the lowest levels of the beach. The most structured

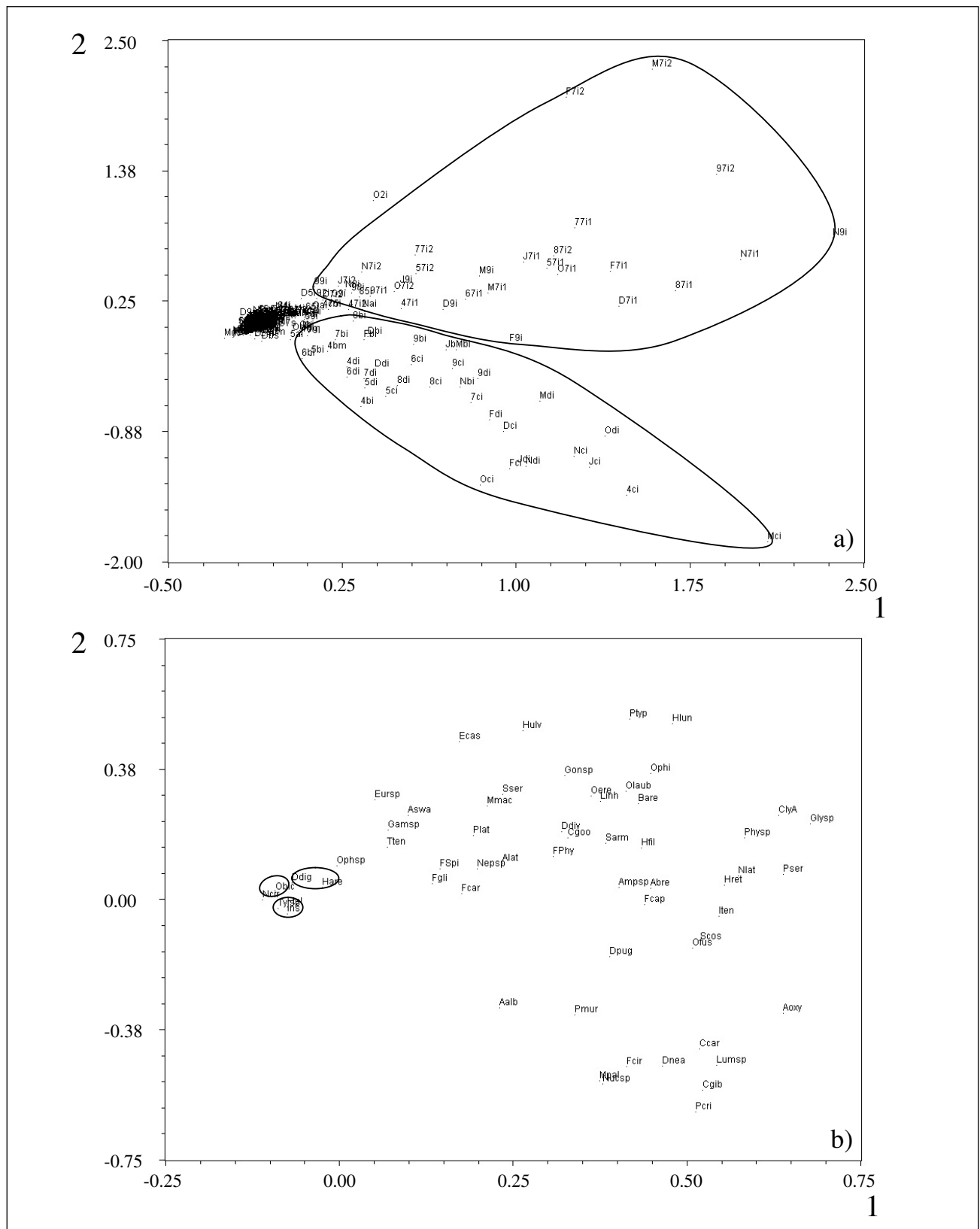


Figure 6. PCA of the distribution of samples (a) in the taxa space (b): principal axes 1 and 2 (22.6 % of total variability). Samples are coded by: month (Apr 99 [4]; May 99 [5]; Jun 99 [6]; Jul 99 [7]; Aug 99 [8]; Sep 99 [9]; Oct 99 [O]; Nov 99 [N]; Dec 99 [D]; Jan 00 [J]; Feb 00 [F]; Mar 00 [M]); transect (no. for 1-9 and a-d for 10-13); and sampling level (i, m, s); e.g., Oci: Oct 99, transect 12, infralittoral

Table I. Fidelity and constancy indices for the five communities considered (abbreviations used in PCA)

Community	Fidelity Index	Constancy Index	
		Constant	Accessory
Supralittoral communities	Exclusive	F. Talitridae (FTal)	<i>Tylos latreillei</i> (Tlat)
	Selective	-	-
	Preferential	-	Insecta (Ins)
Midlittoral communities	Exclusive	-	-
	Selective	-	-
	Preferential	-	<i>Scolecopsis squamata</i> (Ncir) <i>Ophelia bicornis</i> (Obic)
Infralittoral community dominated by <i>Angulus tenuis</i> and <i>Nephtys</i> sp.	Exclusive	-	<i>Haustorius arenarius</i> (Hare)
	Selective	-	-
	Preferential	-	<i>Digitaria digitaria</i> (Ddig)
Infralittoral community dominated by <i>Euclymene</i> sp. A	Exclusive	-	-
		-	-
		-	-
	Preferential	<i>Angulus tenuis</i> (Tten) <i>Goniada</i> sp. (Gonsp)	<i>Onuphis eremita</i> (Oere)
			<i>Sphaeroma monodi</i> (Smon)
			<i>Ophelia laubieri</i> (Olau)
			<i>Pariambus typicus</i> (Ptyp)
			<i>Bodotria arenosa</i> (Bare)
			<i>Divaricella divaricata</i> (Ddiv)
			O. Ophiuroidea (OOph)
			<i>Heteromastus filiformis</i> (Hfil)
			<i>Phyllodoce</i> sp. (Physp)
			<i>Malmgreniella lunulata</i> (Hlun)
			<i>Leptosynapta inhaerens</i> (Linh)
			<i>Atylus swammerdami</i> (Aswa)
			<i>Hydrobia ulvae</i> (Hulv)
Infralittoral community dominated by <i>Spiochaetopterus costarum</i>	Exclusive	-	<i>Melinna palmata</i> (Mpal)
			<i>Nucula</i> sp. (Nucsp)
			<i>Abra alba</i> (Aalb)
	Selective	<i>Pista cristata</i> (Pcri) <i>Cyathura carinata</i> (Ccar) <i>Corbula gibba</i> (Cgib) <i>Lumbrineris</i> sp. (Lumsp)	<i>Diopatra neapolitana</i> (Dnea)
			<i>Lygdamis muratus</i> (Pmur)
			F. Cirratulidae (FCir)
			<i>Iphinoe tenella</i> (Iten)
			<i>Diogenes pugilator</i> (Dpug)
	Preferential	<i>Aonides oxycephala</i> (Aoxy) <i>Poecilochaetus serpens</i> (Pser) <i>Notomastus latericeus</i> (Nlat)	<i>Ampelisca</i> sp. (Ampsp)
			<i>Ampelisca brevicornis</i> (Abre)
			F. Capitellidae (FCap)

and complex communities were found in the vicinity of *Zostera* spp. beds.

DISCUSSION

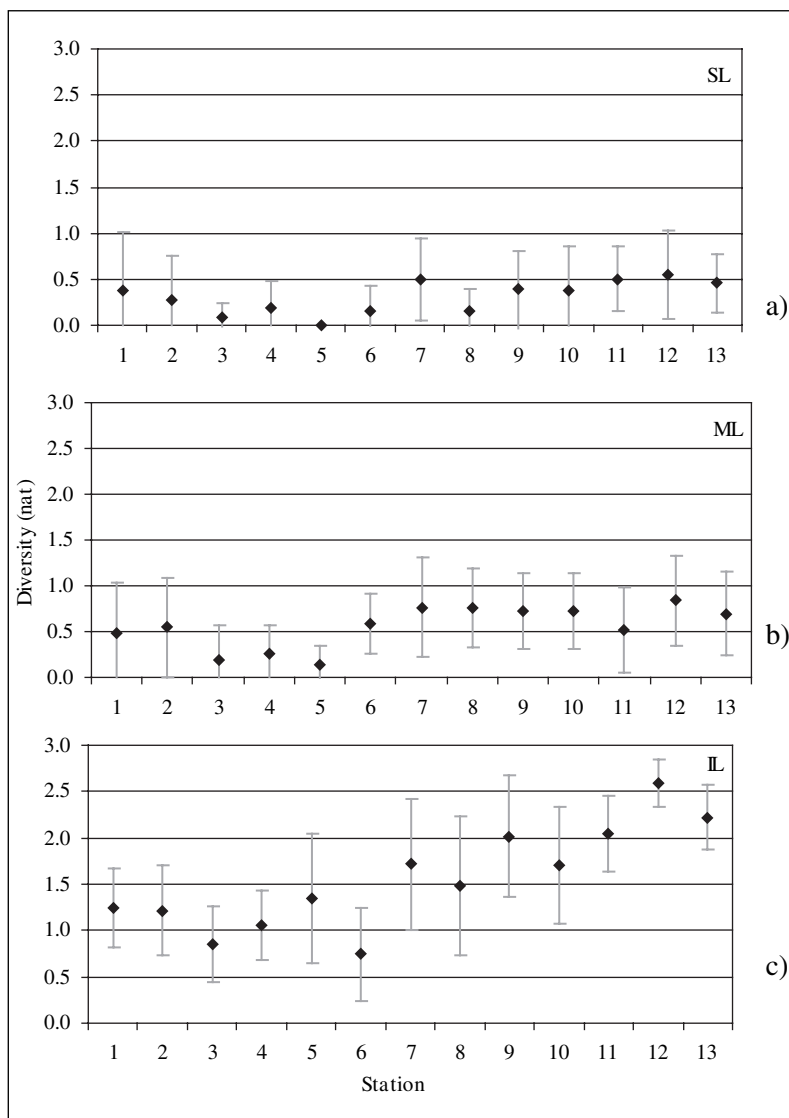
For the environmental management of the Troia peninsula, and specifically of its intertidal area, we started by building a scenario for its future occupation and use, based both on acquired knowledge of the system and on the potential impacts of the pro-

jects to be developed (a marina and a new ferry harbour, integrated into a tourist resort).

The communities found and their distribution patterns, which reflect prevailing environmental conditions, were taken as a baseline for the analysis of future change. We consider this baseline to be representative, and valuable (Pauly, 1995) for two main reasons:

- Disturbance has been kept at very low levels for the past three decades; in fact, since the early 1970s, when the original tourist project was aban-

Figure 7. Shannon-Wiener diversity index (12-month averages and standard deviations) at each sampling station. (a): supralittoral; (b): midlittoral; (c): infralittoral



done, leading to a reduced occupation and even to the degradation of the existing infrastructures (hotels and apartments).

- Natural coastal dynamics and variability, analysed at the half-century scale through the use of seriated aerial photography, showed the stability of the estuarine margin of the peninsula. This also revealed the progressive growth of its marine margin, with a concurrent stabilization of the upper beach environments, and the migration of the corresponding intertidal communities. Such a stability gradient is clearly reflected in the community patterns found during the present study.

The most relevant potential impacts of the projects include (Andrade *et al.*, 2002): 1) loss of intertidal habitat (including a small patch of *Zostera*

spp. bed); 2) modification of hydrodynamic and sedimentary circulation patterns; 3) change of local sediment characteristics; and 4) increased use of the area (beach use and navigation).

To evaluate the actual consequences of these impacts on the natural system, the present owners of the peninsula adopted an adaptive monitoring programme integrated in the Environmental Management System (EMS), which is also being developed and implemented.

For the intertidal stretch, the monitoring programme is a follow-up of the present study, encompassing beach profile, sediment grain size, organic matter and carbonate contents, together with abundance and diversity of the benthic communities, at the three intertidal levels.

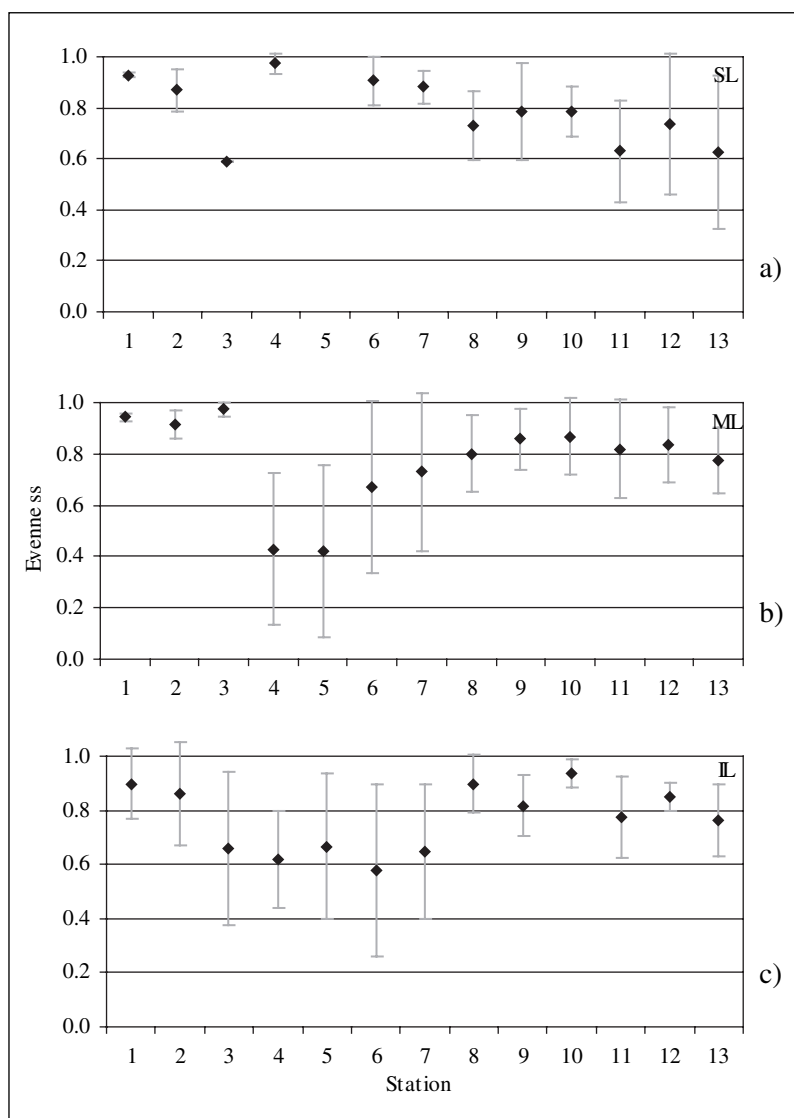


Figure 8. Evenness index (12-month averages and standard deviations) at each sampling station. (a): supralittoral; (b): midlittoral; (c): infralittoral

Monitoring the intertidal environments during the lifetime of the projects will make it possible to detect and quantify changes due to disturbances, either systematic (chronic), even of small magnitude, or isolated in time (acute), but with some magnitude.

The perception of continued loss or degradation of the identified communities will be an indicator of unacceptable disturbance levels, which will imply corrective measures to be added to the EMS, including identification and correction of stress factors.

As an integrative approach, monitoring environmental change using benthic communities will likely yield better results than mere sampling of environmental parameters, where sampling strategy

can influence results, producing positive or negative aliasing, with the studied phenomenon being over- or underestimated, or even lost, because of sampling times or parameter choices.

In contrast, benthic assemblages continuously integrate environmental variability, namely at the level of individual, population or community reactions to changes in environmental stress.

Monitoring benthic communities may involve a steep and labour-intensive learning curve for inexperienced taxonomists, but it will inevitably improve and stabilise, in the medium-to-long run, as they become more familiar with the local fauna (taxa).

Perhaps more importantly, increasing ecological knowledge about poorly known communities will

enable us: 1) to better understand and recognise ecological conditions directly associated with them; 2) to identify key-species and their importance and role in related food webs; 3) to devise adaptive management measures for the conservation and use of specific areas and resources; and 4) to detect specific protection issues in need of a legal framework or status.

To that extent, a number of measures pertaining to the intertidal environment has already been included in the Troia EMS and implemented in the field: a) sediment by-pass on coastal works; b) a boardwalk network given users access to selected beach areas, while protecting sensitive environments from trampling, and cutting motor vehicle circulation on the upper beach; c) educational campaigns for beach users ("edutainment"), teaching them about shore animals and plants, and the role and sensitivity of the intertidal areas (e.g. *Zostera* spp. beds); d) implementation of watercraft manoeuvring standards (mainly related to applying and enforcing current Portuguese legislation concerning leisure navigation).

From the first moment, the key stakeholder in Troia (Imoarea S.A., the tourist entrepreneur that owns the area) decided to gather and integrate all available scientific knowledge in the design and management of its resort.

That same scientific knowledge, together with new information from the monitoring programme, is being used to make the resort users aware of the environmental values of the peninsula, so that they can play a role in their preservation (Costanza *et al.*, 1998, 1999).

However, at the legislation level, incorporation of scientific information on the intertidal environments is lagging. In Troia, even though *Zostera* spp. beds are the most diverse and sensitive intertidal habitats, they are not in any way protected by law. The Habitats Directive (Council Directive 92/43/EEC of 21 May, on the conservation of natural habitats and of wild fauna and flora) lists Habitat type 1120 (*Posidonia* spp. beds are the only protected marine angiosperm habitat). Yet, *Posidonia oceanica* (Linnaeus) Delile, only occurs in the Mediterranean sea, whereas *Zostera marina* Linnaeus, 1758 and *Zostera noltii* Hornemann, 1832 are the ecological equivalents in the Atlantic.

Most coastal and halophytic habitats (estuaries, coastal lagoons, shallow sandbanks) are also listed only very broadly, when compared to the detail found in terrestrial habitats, suggesting again a

clear lack of communication between science and society (in this case, the legal system).

In conclusion, classic scientific knowledge on the structure and distribution of intertidal communities is proving useful for the (tentative) sustainable management of a large tourist project in an environmentally sensitive area.

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